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APPLICATION NUMBER: *60/363,139*
FILING DATE: *March 08, 2002*
RELATED PCT APPLICATION NUMBER: *PCT/US03/07123*

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03/08/02

JC961 U.S. PTO

03-12-02

PTO/SB/16 (10-01)
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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. ET909222239US

11011 U.S. PTO 60/363139 03/08/02

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
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☐ *Additional inventors are being named on the ______ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

METHOD FOR LINEARIZING DEFLECTION OF A MEMS DEVICE USING BINARY ELECTRODES AND VOLTAGE MODULATION

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 6

☐ CD(s), Number

☐ Drawing(s) *Number of Sheets*

☐ Other (specify)

☐ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.

☐ A check or money order is enclosed to cover the filing fees

☑ The Commissioner is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number: 023255

☐ Payment by credit card. Form PTO-2038 is attached.

FILING FEE AMOUNT ($) $80.00

The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☐ No.

☐ Yes, the name of the U.S. Government agency and the Government contract number are: ________________

Respectfully submitted,

SIGNATURE [signature]

Date 03/08/2002

TYPED or PRINTED NAME Mark N. Horenstein

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Docket Number: BU02-15

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

This collection of information is required by 37 CFR 1.51. The information is used by the public to file (and by the PTO to process) a provisional application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the complete provisional application to the PTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, Washington, D.C. 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Box Provisional Application, Assistant Commissioner for Patents, Washington, D.C. 20231.

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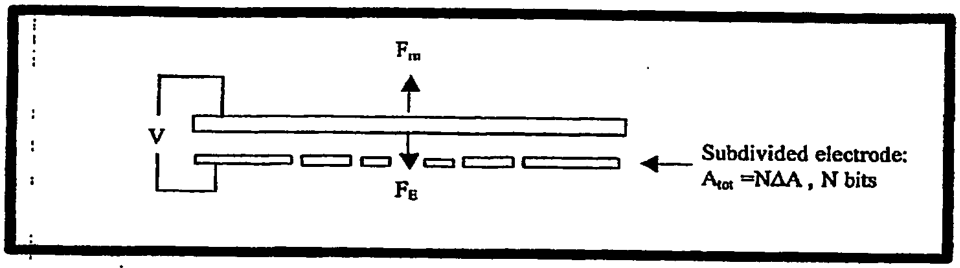
Notes on Multi-Electrode System
28 November 2001



Governing Equations

$F_m = \frac{192EIx}{L^3}$ Mechanical restoring force for a given displacement, x

$F_E = \frac{\varepsilon A V^2}{2(g-x)^2}$ Electrostatic Force

Equilibrium occurs when $F_m = F_E$:

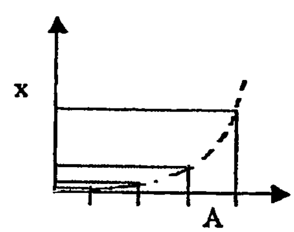
$$A = \frac{C}{V^2} x(g-x)^2 = \frac{C}{V^2}[x^3 - 2gx^2 + g^2 x]$$

where,

$$C = \frac{384EI}{L^3 \varepsilon}$$

Problem:

Deflection, "x", is a strongly non-linear function of area, "A". Therefore, actuation approach based on fixed voltage and uniform increments in A will not lead to uniform increments in <u>phase</u>.



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Mathematically:

$$A = \frac{C}{V^2} x(g-x)^2 = \frac{C}{V^2}[x^3 - 2gx^2 + g^2x]$$

$$\frac{dA}{dx} = \frac{C}{V^2}[3x^2 - 4gx + g^2]$$

so: $$\frac{dx}{dA} = \frac{V^2}{C[3x^2 - 4gx + g^2]}$$

An estimate of the largest step in "x" made by uniformly increasing "A" is:

$$\Delta x_m \approx \left.\frac{dx}{dA}\right|_{x_m} \cdot \Delta A$$

where x_m in the maximum required value of x; Δx_m in the maximum x step.

But: $\Delta A = \dfrac{A_{tot}}{2^n - 1}$ by design

And $A_{tot} = \dfrac{C}{V^2} x_m (g - x_m)^2$ by model

therfore

$$\Delta x_m = \frac{V^2 C x_m (g - x_m)^2}{C V^2 [2^n - 1][3x_m{}^2 - 4gx_m + g^2]}$$

simplifying:

$$\frac{x_m}{\Delta x_m} = \frac{(2^n - 1)(g - 3x_m)}{(g - x_m)}$$

The resolution of the actuator can be defined as one part in M, where

$$M = \frac{x_m}{\Delta x_m}$$

$$\therefore M = \left(\frac{g - 3x_m}{g - x_m}\right)(2^n - 1)$$

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Non-linearity is worst for $g = 3x_m$, and improves as g increases.

Example:

$g = 3.1x_m$

$$M = \left(\frac{0.1}{2.1}\right)(2^n - 1)$$

Factor of 20+ loss of resolution (e.g. 8 bit system provides ~3 bit resolution)

Resolution Reduction Factor, R is:

$$\frac{1}{R} \equiv \left(\frac{g - 3x_m}{g - x_m}\right)$$

Improvement in resolution is possible, by increasing "g".

g	R	
$3.1x_m$	21	*(~silicon single-gap structures)*
$4x_m$	3	
$5x_m$	2	*if g >= $5x_m$, only 1 bit of resolution is lost*
$6.7x_m$	1.5	*silicon double-gap structures*

Price: Increase driving voltage

$$V^2 = \frac{C}{A} x\ (g\ - x\ )^2$$

therefore:

$$\left(\frac{V_2}{V_1}\right)^2 = \frac{C/_A\, x_m(g_m - x_m)^2}{C/_A\, xm(g_m - x_m)^2}$$

and

$$\frac{V_2}{V_1} = \frac{g_2 - x_2}{g_1 - x_1}$$

is the ratio of maximum required voltages for two different gaps. C,A, and x_m unchanged.

If $g_2 = 5x_m$, and $g_1 = 3x_m$,

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$V_2 = 2V_1$

Alternative solution: Linearize

$AV^2 = Cx(g-x)^2$

this could be linearized by imposing the constraint that:

$V^2 \propto (g-x)^2$ or $V = k(g-x)$

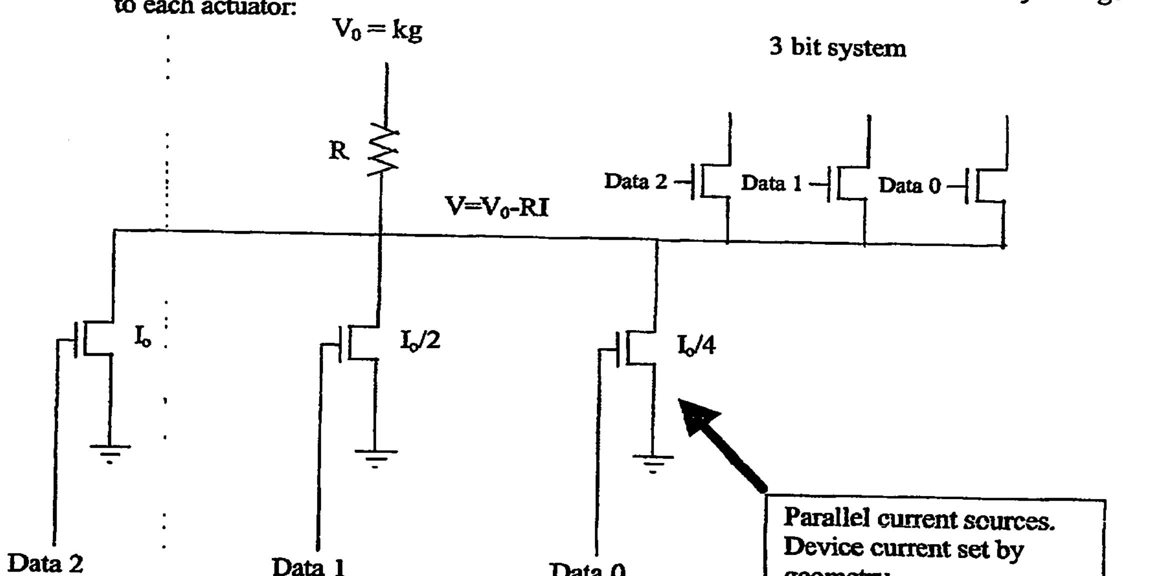
then $A = \frac{C}{k^2}x$

find value of k:

$A_{tot} = \frac{C}{k^2}x_m \qquad k = \sqrt{\frac{Cx_m}{A_{tot}}}$

For the silicon structures with a 2.5 μm gap: $V_i \sim 70V$ and $V_r \sim 50V$

How to make $V = k(g-x)$?
Input to system (binary) is a linear representation of x. Use the data bus to modify voltage to each actuator:



Solution developed by Mark Horenstein

1-15-2002

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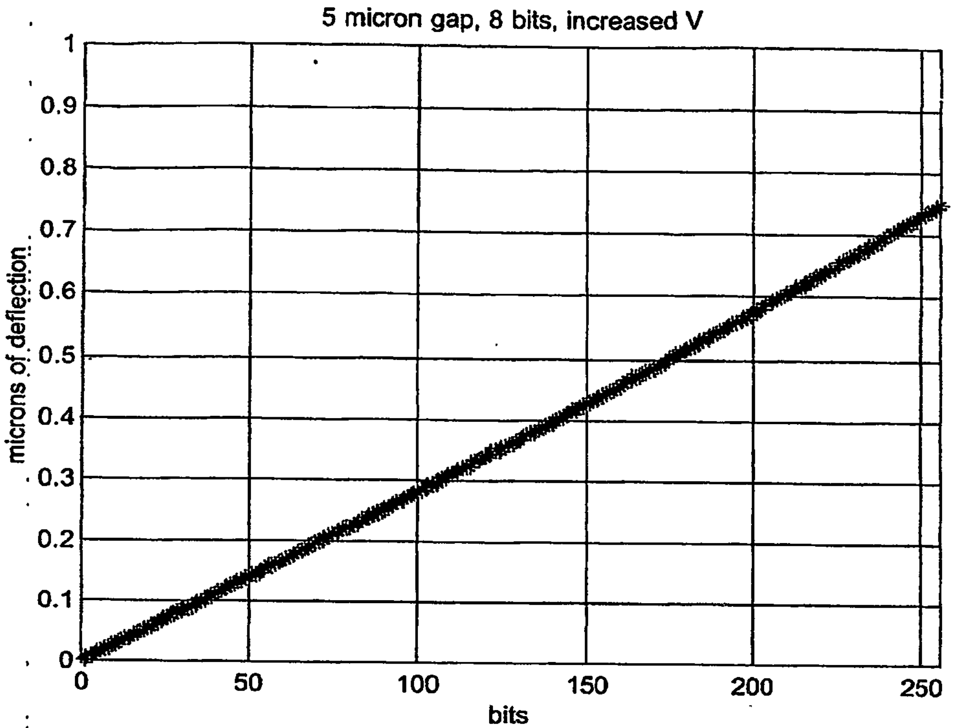
Model of an 8 bit system, with a 5 μm gap using the linearized voltage solution (V_t = 130V)



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```
%--MATLAB PROGRAM--
%Example of linearizing the deflection versus digital input curve.
%Requires that the voltage applied to the electrodes be reduced as
%the digital input n goes up from 0 to N (where N = 16, 128, 256, etc)
close; clear;                                   %close any previous plots and reset
variables
N=256;                                                  %Maximum value of digital
input 2^n where n=0...N (8 bits in this example)
k = 60;                                                 %elastic restoring force in
N/m (typical)
eo = 8.85e-12;                                  %electric permittivity of air
side = 250e-6;                                  %dimension of each side of actuator
Area = side^2;                                  %total area of actuator
Ao=Area/N;                                              %smallest increment of area
(area increment per digital bit)
gap = 5e-6;                                     %spacing between actuator and
activation electrode
dy = gap/1000;                                  %incremental deflection to be used
in iteration

for n=1:N;                                              %Plot y versus digital input
n for n=1...N:
   V=40*(1-n/(8*N));          %V is a function of n. Equal to 40 V at start, decreases
                                                          %in a straight line
function with n. I think we can do this
                              %in a straightforward manner electronically in VLSI.

%----Iteration to solve for deflection y as a function of digital input n -----
y=0;                                        %initialize deflection to zero
Fm = k*y;                                               %Compute magnitude of
mechanical force
Fe = eo*Ao*n*V^2/(2*(gap-y)^2);             %Compute magnitude of electrostatic force

      %(Total area is n times Ao)
%-----------------------------------------------------------------
while Fm < Fe;
                y = y + dy;                             %Try a slightly larger
deflection
                Fm = k*y;                          %Recompute magnitude of
mechanical force
      Fe = eo*Ao*n*V^2/(gap-y)^2;           %Recompute magnitude of electrostatic force
                                                                            %Get
out of loop when Fm = Fe.
end
Y(n)=y;                                                 %Save this value of y(n) for
later plotting
end                                                           %Iterate over all
values of n from 0...N
%Done with iteration
plot(Y*1e6)                                             %Plot deflection in microns
versus n

%Suggestions variations on the program:

%Set V to a fixed 40 V; this change will demonstrate non-linearity in area vs n
curve.
%Set V to 40(n/N) and change Ao*n to Area; this change produces the usual nonlinear
%deflection versus voltage curve.
```


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